RED MUD BASED COMPOSITE MATERIAL FOR UNDERGROUND COAL MINES ROOF SUPPORT

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology

in

Mining Engineering

by

Aalok Kumar Chaudhary

212MN1343

Department of Mining Engineering

National Institute of Technology Rourkela - 8

May, 2014

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Under the guidance of

Prof. D. S. Nimaje
Prof. S. K. Acharya

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CERTIFICATE

This is to certify that the thesis entitled "**RED MUD BASED COMPOSITE MATERIAL FOR UNDERGROUND COAL MINES ROOF SUPPORT"** submitted by **Aalok Kumar Chaudhary** to National Institute of Technology, Rourkela for the award of the degree of M.Tech.in Mining Engineering, is a record of bonfire research work under my supervision and guidance. The results embodied in this thesis have not been submitted to any other University/Institute for the award of any other degree or diploma.

Prof. D.S. Nimaje
Assistant professor
Dept. of Mining Engineering

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Aalok Kumar Chaudhary

Abstract

Red mud is a solid waste product of the Bayer process, which extracts the alumina from bauxite. Red mud, as name suggests, is brick red in color and slimy having average particle size of <10 µm. The red color is caused by the oxidized iron present. India is amongst the major producers of alumina in the world. Red mud cannot be disposed of easily. In most countries where red mud is produced, it is pumped into holding ponds. Red mud is alkaline in nature so it is hazardous for environment. Its disposal remains a worldwide issue in terms of environmental concerns. During the past decades, extensive work has been done by a lot of global researchers to develop various economic ways for the utilization of red mud. Few researchers tried to develop a fly ash composite used for the underground roof support to keep in view we have tried to develop red mud based composite material used for roof support in underground mines as a replacement of wooden prop. In this thesis, several aspects of production and characterization of red mud in World and Indian context are discussed with the characterization and properties were measured through XRD, SEM analysis and pH determination.

Red mud has rich in iron content especially Damanjodi, NALCO plant, Odisha as compare to the other aluminium plant in India and found that it can be used as a composite material because of its higher strength as a roof support. For further enhancement of the strength of red mud, lime is used as a binding agent in proportion with red mud. Unconfined compressive strength and Brazilian tensile strength is carried out for different composition of red mud and lime for different curing period. The red mud based composite support should take a load nearly the load taken by wooden prop in mines as a roof support. It is also economical and easier to handle.

Keywords: Red mud, composite material, strength, roof support

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Dedicated to my Mom

Chapter1

Introduction

Chapter: 1

Introduction

1.1 Background

Red mud is solid waste product of the bayer process, the principal industrial means of refining bauxite in order to provide alumina as raw material for electrolysis of aluminium by the Hall-heroult process. Approximately 35–40% of the processed bauxite ore goes into the waste as alkaline red mud slurry which consists of 15–40% solids and 0.8–1.5 tons of red mud is generated per ton of alumina produced. Numerous reports proposing re-uses of `red mud' have been advanced, especially for the production of ceramic bodies or cements. Along this line of research, a deep characterization of the red mud has been presented in a companion paper; hereafter special attention has been paid to the structural transformations and cross-reactions induced by heating representative batches of red mud. Due to the characteristics of fine particles, high alkalinity (pH 10–12.5) and trace metal content, the disposal of large quantities of red mud has caused serious environmental problem including soil contamination, groundwater pollution and fine particles' suspension in the sea. Moreover, the storage of red mud in lakes or ponds occupies huge areas of land, and the storage of dry red mud can also lead to dust pollution which is a serious health problem for the people living near the red mud storage ponds. The general trend of today for the industrial wastes or by-products, which are produced in industrial countries, is to examine alternative ways for their exploitation in order to eliminate cost of disposal and avoid soil and water contamination. Many of these undesirable industrial materials contain significant amounts of inorganic ingredients, such as oxides of silicon, aluminium, calcium and iron, which, at suitable combinations [1]. The various applications that have been investigated include: (i) as a stabilization material for the preparation of liners [2]; (ii) as adsorbents for the removal of heavy metals, dyes, phosphate, nitrate and fluoride [3]; (iii) preparation of catalysts; (iv) recovery of iron, aluminium, titanium and other trace metals [4]; (v) production of radiopaque materials [5]; (vi) preparation of ceramics [6]; (vii) production of construction bricks [7]; (viii) development of pigments and paints [8] and (ix) preparation of cements [9].

The dissertation audits the World and Indian parts of creation of bauxite and era of red mud. It depicts the characterization, transfer, different neutralization techniques and usage of red mud. It gives the point by point evaluation of the work being done for making utilization of red mud in building, contamination control and metal recovery. As the red mud is having higher strength, it can be used in mines also.

1.2 Objectives

There are various applications of red mud as stated earlier for general use but still we are unable to use red mud fully which will consume some land and affecting the general environment. Till date, red mud is not using for mining applications and the idea of this work was coming from the fly ash based composite material used in underground mine as a support. As red mud has rich in iron content (about 45- 50%) and it has greater strength as compare to fly ash, red mud based composite material can be used in underground mine as a roof support to replace the sal wood prop [10].

The objectives of the dissertation are as follows:

- Collection of the red mud with higher iron content.
- Enhancement of the strength of red mud by mixing the proportionate of binding agent.
- Development of red mud based composite material as a support in underground coal mine.

To achieve the above said objectives, the following methodology was adopted:

- **Literature review** – collection of all the past work done by various academicians/researchers/scientists in national and international journals, books and proceedings.
- **Experimentation-** The experimentation part divided into two stages
  1. Determination of properties of red mud- XRD analysis, SEM analysis, pH and optimum moisture content of red mud based composite.
  2. Determination of tensile and unconfined compressive strength of red mud based composites.
- **Analysis**- Analysis was done for red mud composite material used as support in underground mine, its failure load, cost and handling.

Chapter 2

Literature Review

Chapter: 2

Literature Review

Red mud is the mechanical waste created throughout the creation of alumina. As per the evaluation of crude material bauxite and the generation methodology of alumina, red mud could be separated into Bayer red mud and Sintering red mud. In view of present advances, there is 0.8-1.76 t red mud produced by every 1t alumina prepared. It is accounted that, these are dependent upon 3 million tons of red mud handled by China's biggest three alumina preparation bases. As there is a lot of modern soluble base, fluoride, overwhelming metals and other potential poisons in red mud, long haul-stockpiling might possess rare area assets, as well as effectively prompt genuine contamination of the encompassing soil, air and groundwater. What’s more, the ceaseless expanding of stockpiling yard height may lead potential land disasters. Studies on the physical and compound properties and exhaustive use of red mud have turned into a center of related materials inside science and designing fields [11].

2.1 Origin of Bauxite

Bauxite is a member of the family of lateritic rocks. It is characterized by a particular enrichment of aluminum-hydroxide minerals, such as gibbsite, boehmite and/or diaspore. Bauxite forms by weathering of aluminous silicate rock (lateritic bauxite) and less commonly of carbonate rock (karst bauxite) mainly in tropical and sub-tropical climate. Bauxite forms by weathering under conditions favorable for the retention of alumina and the leaching of other constituents of the parent rock. Bauxite rock has a specific gravity between 2.6 to 3.5 Kg/m^3It is usually, anamorphous or clay like substance which is however, not plastic. The usual color of bauxite is pink but if of lower iron content it may tend to become whitish in color and with increase in iron it is reddish brown in color [11].

2.2 Production of Bauxite

Bauxite resources are estimated to be 55 to 75 billion tones, in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and elsewhere (6%). Domestic resources of bauxite are inadequate to meet long-term U.S. demand, but the United States and most other major aluminum-producing countries have essentially inexhaustible sub-economic resources of aluminum in materials other than bauxite [11].

Table 2. 1 Worldwide bauxite production [11]

Country	Mine production *1000 ton (2012)	Mine production *1000 ton (2013)	Reserves
United States	NA	NA	20000
Australia	76300	77000	6000000
Brazil	34000	34200	2600000
China	47000	47000	830000
Greece	2100	2000	600000
Guinea	17800	17000	7400000
Guyana	2210	2250	850000
India	19000	19000	540000
Indonesia	29000	30000	1000000
Jamaica	9340	9500	2000000
Kazakhstan	5170	5100	160000
Russia	5720	5200	200000
Suriname	3400	3400	580000
Venezuela	2000	2500	320000
Vietnam	100	100	2100000
Other counties	5020	5000	2400000
World total	258000	259000	28000000

2.3 Production of Alumina in India

The overall alumina production is around 58 million tones in which India produced 2.7 million tones. The Indian aluminum segment is described by huge coordinated players like HINDALCO and National Aluminum Company (NALCO, Alumina plant at Damanjodi, Odisha), also the recently began Vedanta Alumina Ltd (Alumina plant at Lanjigarh, Orissa). The other alumina incorporates are Indian Aluminum Company (INDALCO in which India having two plants at Belgaum, Karnataka and Muri, Jharkhand), now combined with Hindustan Aluminum Company (HINDALCO, Renukoot, Uttar Pradesh), Bharat Aluminum (BALCO) and Madras Aluminum (MALCO) the past Public sector unit, which have been obtained by Sterlite Industries. Subsequently, there are just three primary essential metal makers in the division in particular BALCO (Vedanta), National Aluminum Company (NALCO) and HINDALCO (Aditya Birla Group) [12].

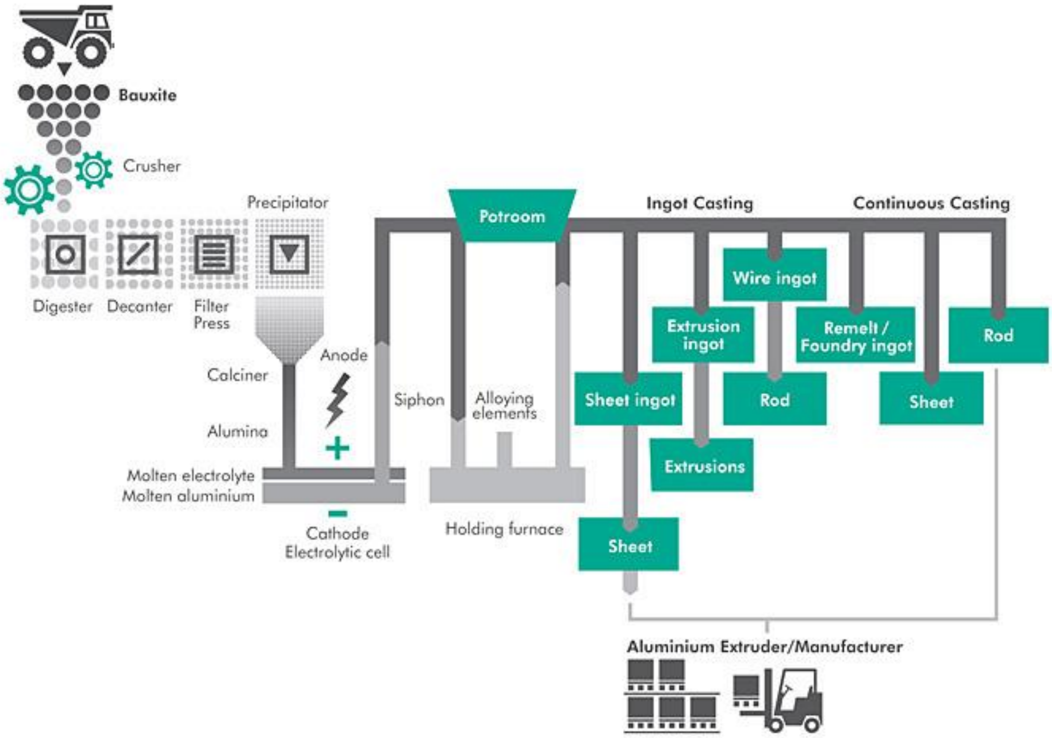


Figure 2. 1 Production Process of Alumina [13]

2.4 Production of Red Mud

Red mud is obtained from sintering process and Bayer process. In world scenario Bayer process is most commonly used and this process is very useful also.A caustic pressure hydrometallurgical process which extracts aluminium species from bauxite ore and produces alumina, an aluminium oxide (Al_2O_3), via an intermediate product called hydrate, which is an aluminium oxide tri-hydrate ($Al_2O_3.3H_2O$) [11].

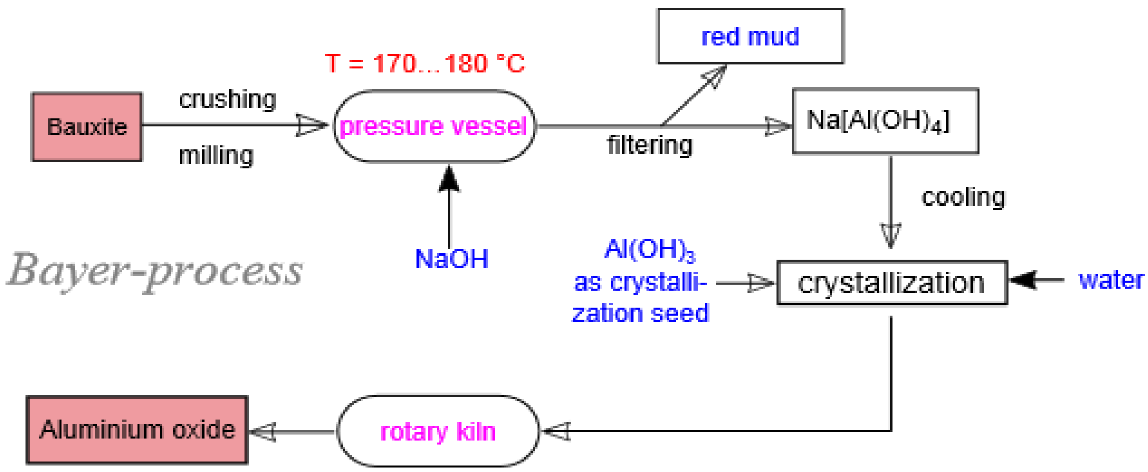


Figure 2. 2 Bayer Process [14]

2.5 Red Mud Neutralization

Neutralization of red mud will help to decrease the environmental impact caused due to its storage and also lessen significantly the ongoing management of the deposits after closure. The cost of neutralization will, to some degree at least, be offset by a reduction in the need for long-term management of the residue deposits. Instead of accruing funds to deal with a future liability, the funds can be invested in process improvements, which reduce or remove the liability. It will also give open opportunities for re-use of the residue which to date have been prevented because of the high pH [5].A factorial design and response surface approach has been employed to optimize the neutralization, partial reduction, magnetization and carbonization of highly alkaline Red Mud bauxite residues as derived from the Bayer process using highly acidic pyrolysis bio-oil as the limiting reagent [15].

2.6 Utilization of Red Mud

Red mud has very high amount of iron. It has Fe_2O_3, Al_2O_3, SiO_2, CaO, Na_2O and K_2O.Red mud can be used as providing high strength due to presence of iron. Red mud is used in construction of building such bricks, cement, roofing tiles, glass ceramics etc. It can be used as filling material in mine. It can be used in making glass. With red mud and chromium slag as the main material successfully produced black glass decorative materials [11].

2.7 National and International status

Wang et al. (2012) investigated the bayer and sintering red mud. Their composition, mechanical properties and microstructure characterization were measured through XRD, TG and SEM examination. Their shear quality, molecule size, thickness and water powered aspects likewise had been performed. Tremendous contrasts between the fundamental mineral sorts of these two sorts of red mud likewise can be found. It also discussed about the sintering red mud can become the main filling material of supporting structure of red mud stocking yard. Bayer red mud has a high reuse value and also can be used as a mixing material of masonry mortar.

Cablik et al. (2007) carried out the characterization of red mud – a waste generated by the Bayer process in the aluminum industry – which causes environmental problems was discussed in detail. Residue of the alumina leaching from bauxite was analyzed for mineral compositions of the mineral ore and its residue for chemical composition, density, and grain-size composition. The residue was calcinated and finally tested as a pigment for use in the building material industry. The test blocks were tested on the compressive strength.

Deb and Chugh (2004) investigated the structural analysis of post using finite element analysis and theoretical models. For small size post, an axially symmetric model is utilized to analyze stress distribution in the post and sheath, where applicable. Analyses were directed towards obtaining the distribution of confining pressure on coal ash based grout due to sheathing material. Buckling behavior of large size post is also studied. An extensive laboratory testing was conducted to obtain properties of coal ash based post and crib members. Full scale buckling testing of coal ash based post was also carried out to compare results obtain from testing of timber support.

Rai et al. (2012) discussed about the production and characterization of bauxite and red mud in view of World and Indian context. It reviews comprehensively the disposal and neutralization methods of red mud and gives the detailed assessment of the work carried until now for the utilization of red mud in the field of building (geo-polymers, clay material, cements, ceramics, fired and non-fired building materials, concrete industry), pollution control (in wastewater treatment, absorption and purification of acid waste gases), metal recovery (iron, titanium, aluminum, alkali, rare earths), coagulant, adsorbent, catalyst and in soil remediation. It also reviews the work carried out for rehabilitation of red mud ponds. This paper is an effort to analyze these developments and progress made which would be very useful in the context of environmental concerns for disposal and utilization of red mud.

Samal et al. (2012) studied the proposal for resources, utilization and processes of red mud in India. Critical accomplishments in treatment and usage of red mud have been gotten in India in the most recent decade. In this paper, the different suggestions for the use of red mud produced in India are exhibited. Additionally, the detriments connected with these potential business provisions of red mud are discussed.

Qu et al. (2013) carried out the work to explore natural draining of uncommon earth components and radioactive components from red mud, and to assess the radioactivity of the bioleached red mud utilized for development materials. A filamentous, corrosive preparing parasites named RM-10, identified as Penicilliumtricolor, is segregated from red mud. In our bioleaching investigations by utilizing RM-10, a total centralization of 2% (w/v) red mud under one stage bioleaching procedure was for the most part found to give the greatest draining proportions of the Rees furthermore radioactive components.

Sglavo et al. (1999) investigated two different clays used as basic materials, the former being currently employed for the production of bricks by extrusion, the second is almost pure Kaolin for high quality ceramic manufacturing. In both cases the addition of red mud led to more deflocculated solid-water systems and an increase of the critical moisture content. Mixtures pre-pared with the first clay and red mud loads up to 50% were fired at 850^0C. The red mud content did not influence the sample porosity while determining a strength decrease attributed to the inertness of red mud at the working temperature. Samples produced using the second clay and red mud (0 ± 20%) were fired at 950 and 1050^0 C.

Villarejo et al. (2012) studied the principle objective to make artistic materials by including the profoundly hazardous waste "red mud" to a ceramic matrix and killing this waste in the grid. The ideal extent of mud to earth was discovered to be 50%. The examples made were investigated utilizing XRD to focus the crystalline stages produced, and the microstructure was broke down utilizing a checking electron magnifying lens (SEM). Adding this modern waste to the fired structure alters and enhances the physical and mechanical properties because of the incredible measure of vitreous stage that the waste produces.

From the literature review, it reveals that till date no study was carried out on the application of red mud in mining. To keep in view, we are tried to develop a composite of red mud and other binding agent which increases its strength and can be used as a roof support in underground mines to replace the sal wooden prop.

Chapter 3

Experimentation

Chapter: 3

Experimentation

3.1 Sample collection and Preparation

Red mud was collected from NALCO refinery, Damanjodi, Odisha. Here bauxite is the raw material from which alumina is extracted by alkali process i.e. known as Bayer Process. All the samples was prepared in the laboratory as per the experimental requirements. A-grade lime was selected as a binding agent in this composite. Various compositions of red mud and lime were prepared for strength test.

3.1.1 Sample Preparation for XRD Analysis

Red mud collected samples was crushed to a small size and sieved it through a sieve of 2 mm size. Then it was carefully placed in oven for one and half hour at 110^0 C to remove the external moisture and the sample is ready for testing.

3.1.2 Sample Preparation for SEM Analysis

For SEM analysis, collected red mud crushed to a small size and pass it through a sieve of size 2 mm. before using for SEM, the red mud sample placed it in oven for one and half hour at 110^0 C to remove the external moisture.

3.1.3 Sample preparation for UCS

A cylinder mould of 13 cm length and 6 cm diameter was used for preparation of the unconfined compressive strength (UCS) test sample. Sample was prepared with uniform tamping. The final prepared specimen having length to diameter ratio 2 to 2.5 was used for testing.

3.1.4 Sample preparation for Tensile Strength

This tensile strength is determined as per ASTM D3967. For this purpose, we used the circular disk red mud composite sample of length to diameter ratio 0.5. The length and diameter of circular disk are 3 and 6 cm respectively.

3.2 Experimental Technique

Following experiments was carried out in this project

1. XRD
2. SEM
3. pH determination
4. Standard proctor compaction test

5. Unconfined Compressive Strength test
6. Tensile Strength test

3.2.1 XRD

X-ray diffraction (XRD) provides a powerful tool to study the structure of the materials which is a key requirement for understanding materials properties. X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). It is a technique for analyzing structures unknown solids which is critical to studies in geology, environmental science, material science, engineering and biology. X-ray beam hits a crystal, scattering the beam in a manner characterized by the atomic structure. Even complex structures can be analyzed by x-ray diffraction, such as DNA and proteins. In the present investigation, XRD analysis was done using Rigaku Japan make high resolution XRD ULTIMA-IV in range of 10 to 90^0 with scanning rate of 2^0 /min. at 2θ of scattering angle [23].

3.2.1.1 Principle of XRD

In X-ray diffraction process a beam of x-rays strikes a crystal and causes beam to spread into many specific directions. These X-rays are generated using cathode ray tube. These x-rays are collimated to concentrate, and are directed towards the sample. Bragg's law was used to explain the interference pattern of X-rays scattered by crystals. The interaction of the incident rays with the sample produces constructive interference when conditions satisfy Bragg’s law i.e. $n\lambda = 2d \sin\theta$ [23].

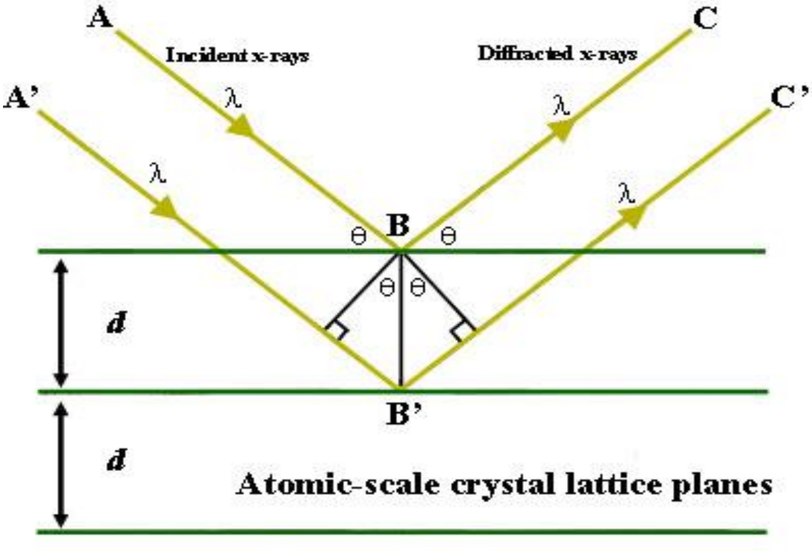


Figure 3.1 Principle of XRD (Bragg’s Law) [27]

3.2.2 SEM

Scanning Electron Microscopy (SEM) is a powerful analytical technique for the evaluation of particulate matter. Scanning electron microscope uses a beam of energetic electrons to examine objects on a very fine scale. It is capable of performing analyses of selected point locations on the sample and is especially useful for determining chemical compositions. The SEM analyses were conducted in a JEOL JSM 6480 LV, (Japan) model operated at 15 kV and linked with an energy dispersive X-ray attachment. Microstructure and chemical composition of the samples were examined by SEM techniques [23].

3.2.2.1 Principle of SEM

A scanning electron microscope is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer.

3.2.3 pH Determination:

The pH value was determined as per IS: 2720 to identify the alkaline or acidic characteristic of red mud. This experiment was carried out using pH meter.

3.2.3.1 Procedure[24]

- Take 20g of red mud in 100ml of beaker.
- 50ml of distilled water should be added in it.
- Then stir it for 10 min. and leave it for an hour.
- 20 ml of clear solution should be pipette out and 2 or 3 drops of universal indicator should be added into a clean test tube and shake it gently.
- Then the color of solution should be compared with standard chart. During comparison of color of solution effect of reflection should be avoided.

3.2.4 Standard proctor compaction

For contraction of road pavement, airports, and other structure, it is very necessary to compact soil to improve its strength. Procter developed a laboratory compaction test procedure to find out maximum dry unit weight of compaction of soil which can be used for specification of field compaction. It is based on the compaction of the soil fraction passing U.S. sieve size 2 mm [25].

Plate 3. 1 Proctor compaction mould and hammer

3.2.4.1 Procedure[25]

- Take about 2 kg air dry sample (red mud + lime) on which the proctor hammer compaction test will be conducted.
- Add water in composite (5%,7.5%,10%,12.5% and so on)
- Determine the weight of the proctor mould + base plate (not extension), W_1.
- Now attach the extension to the top of mould.
- Pour the sample into the mould in three equal layers. Each layer should be compacted uniformly by the standard proctor hammer 25 times before the next layer of loose sample is poured into the mould.
- Remove the top attachment(extension)
- Trim the excess sample above the mould.
- Determine the weight of mould + base, plate + compacted moist sample in the mould, W_2.
- Remove the base plate from the mould. Using a jack, extrude the compacted sample from the mould.
- Take the moisture can and determine the mass, W_3 (g).
- Put small amount of moist sample in can and weight it (Mass of can + mass of moist sample = W_4**).**

- Placed the moisture can in oven with moist sample in the pan to dry and then weight it (Mass of can + mass of dry sample = W_5).
- Crush the remaining part of red mud composite by hand and add water and mix it thoroughly to raise the moisture content.

3.2.5 Unconfined compressive strength

The purpose of this experiment is to determine the unconfined compressive strength of a red mud composite. Unconfined compressive strength is a common criterion to determine its resistance to any external loading. We will measure unconfined compression, which is an unconsolidated untrained test where the lateral confining pressure is equal to zero (atmospheric pressure) [23].

Plate 3. 2 Determination of unconfined compressive strength using UTM

3.2.5.1 Procedure:

- The specimens prepared for compressive strength test were of 6 cm diameter and 13 cm long.
- Place the specimen in UTM and attach the upper platen of UTM to specimen.

- A small axial load, approximately 25 lbf (100 N), may be applied to the specimen by means of the loading device to properly set the bearing parts of the apparatus.
- Start the machine, machine applied the load to the specimen.
- Continue the test until the point of failure was obtained.
- Take the reading and repeat the test for other specimen

3.2.6 Brazilian tensile strength

The direct tensile strength of soil or rock material is difficult. So, indirect way (Brazilian tensile strength) of its determination is practiced. The Brazilian tensile test make the sample fail under tension though the loading pattern is compressive in nature. In this test, the length (thickness) to diameter ratio is 0.5.The specimens were placed diametrically during test. The sample fails diametrically in tension by application of load [23].

$$\sigma_t = 2P/\pi DL$$

Where, σ_t= tensile strength, P= failure load, D= Diameter of sample, L= Length of sample

Plate 3. 3 Determination of Brazilian tensile strength using UTM

3.2.6.1 Procedure:

- UTM was set on the suitable measuring scale and proper rate of loading with the arrow set to zero.
- The Vernier caliper was used to measure the diameter and thickness (length) of the specimen and maintain the ratio of thickness to diameter as 0.5.

- The specimen is set between the upper and lower platens diametrically.
- The specimen was loaded at the prescribed study state to the point of failure.
- The failure load was recorded. Same procedure was followed for other specimen

Chapter 4

Results and Analysis

Chapter: 4

Results and Analysis

4.1 XRD

The results of the XRD shows the following elements are present in red mud.

Table 4. 1 Element Present in Red mud

Element	Weight (%)	Atomic (%)
O	27.88	50.87
Na	5.43	6.90
Al	9.15	9.90
Si	3.43	3.56
Ca	0.99	0.72
Ti	3.38	2.06
Fe	49.75	26.00
Total	100.00	

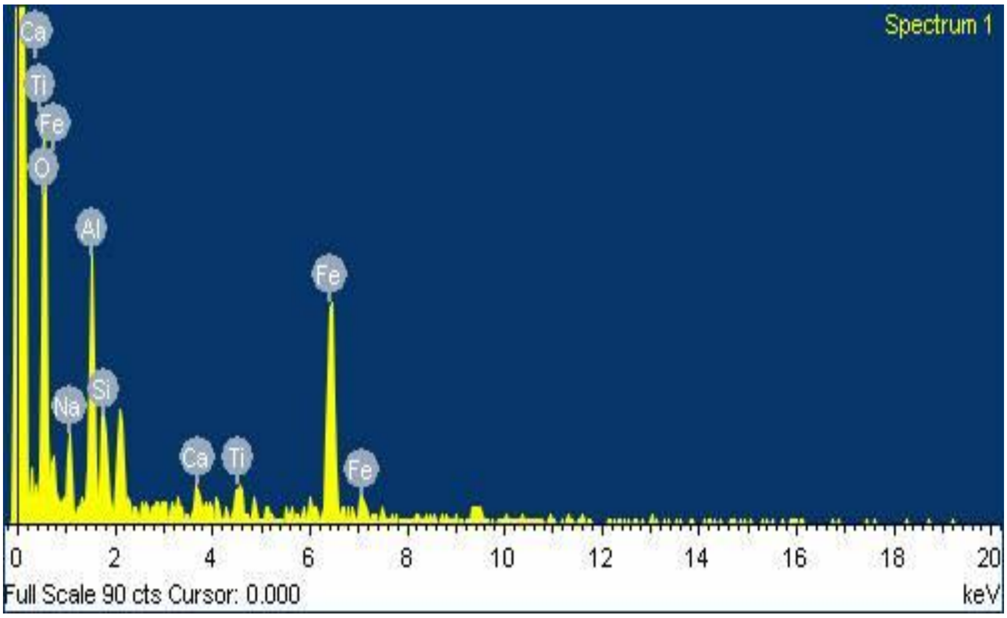
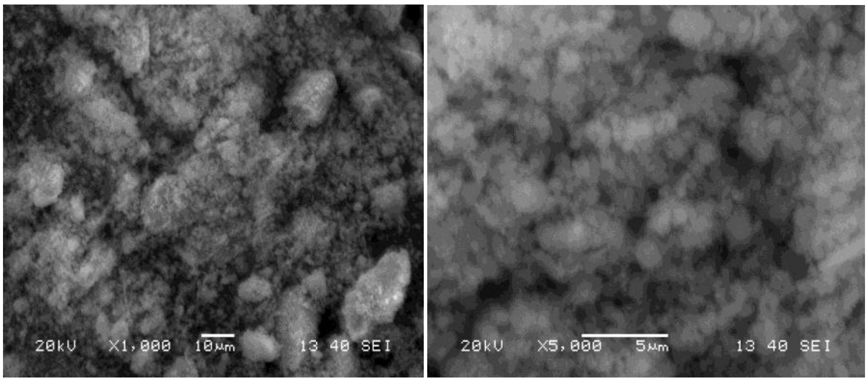


Figure 4. 1 XRD Analysis of red mud

Table 4.1 and Fig. 4.1 inferred that Damanjodi red mud having rich in iron content (49.75% by weight) as compare to other plant in India. So, we can estimate that if we develop red mud composite, it will provide good strength.

4.2 SEM

Combining with conclusion obtained from the analysis of strength, particle diameter and density, SEM characterization is helpful for further understanding of physical performance and the microstructure of red mud. Fig 4.2 shows that Red mud has dispersive particle.



(a) (b)

Figure 4. 2 SEM Analysis of red mud

4.3 pH Determination

The pH of red mud obtained by pH meter is 10 which is alkaline in nature.

4.4 Standard proctor compaction

It is used to determine the maximum dry density and optimum moisture content of the material. The red mud sample was compacted in the mould in five layers using hammer of 4.9kg mass with a fall of 450mm by giving 25 blows per layer.

Plate 4. 1 Standard proctor compaction sample

Table 4. 2 Standard Proctor Compaction Test (Red Mud 95% + Lime 5%)

Parameters	5% water	7.5% water	10% water	12.5% water	15% water	17.5% water
Weight of mould(W_1) (kg)	4.037	4.037	4.037	4.037	4.037	4.037
Weight of mould(W_1)+Moist red mud, (W_2 kg)	5.508	5.665	5.720	5.793	5.960	5.989
Weight of moist red mud, (W_2-W_1) kg	1.471	1.628	1.683	1.756	1.923	1.952
Moist unit weight= (W_2-W_1)/10^{-3}(kg/m^3)	1471	1628	1683	1756	1923	1952
Mass of moisture can,(W_3 kg)	0.020	0.021	0.020	0.021	0.021	0.159
Mass of can+moisture in red mud,(W_4 kg)	0.061	0.069	0.068	0.078	0.069	0.200
Mass of can+dry red mud (W_5 kg)	0.058	0.064	0.061	0.069	0.060	0.193
Water content (w %) = (W_4-W_5) *100/(W_5-W_3)	7.894	11.627	17.073	18.750	23.076	20.588
Dry unit weight=moist weight/1+(w%/100)	1363.37	1458.42	1437.56	1478.736	1562.44	1618.73

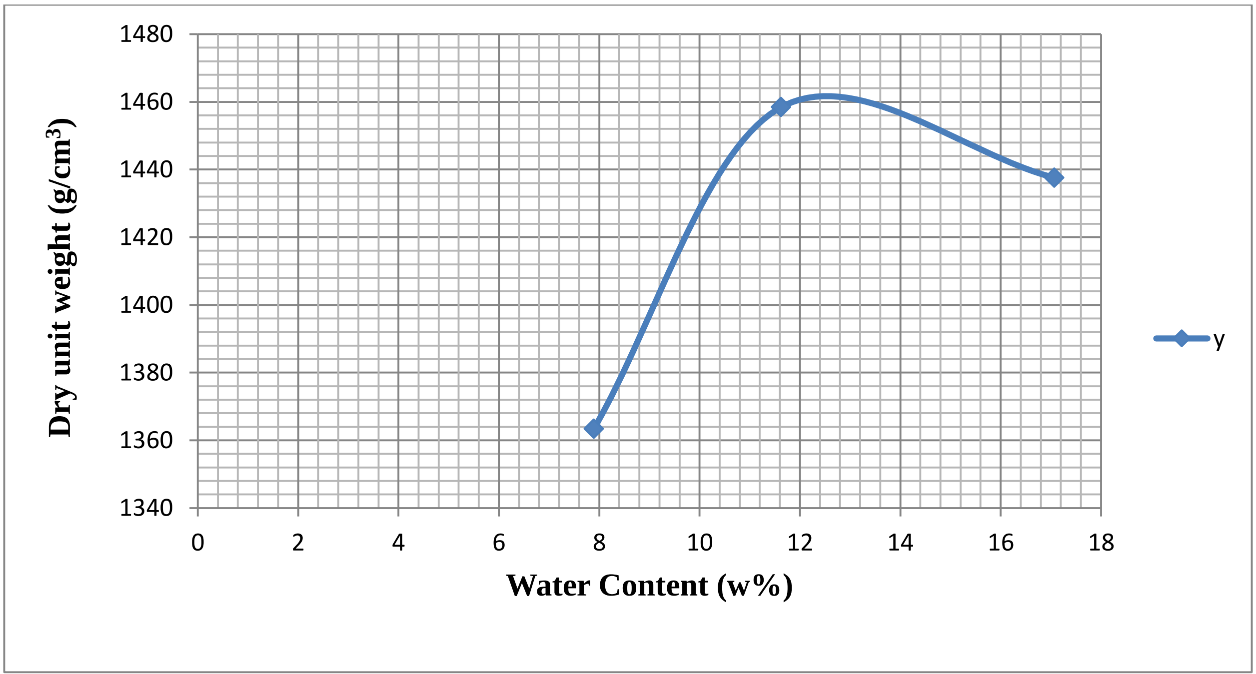


Figure 4. 3 Standard Proctor Compaction Curve (Red Mud 95% + Lime 5%)

Table 4. 3 Standard Proctor Compaction Test (Red Mud 90% + Lime 10%)

Parameters	7.5% water	10% water	12.5% water	15% water	17.5% water
Weight of mould(W_1) (kg)	4.057	4.057	4.057	4.057	4.057
Weight of mould(W_1)+Moist red mud, (W_2 kg)	5.6608	5.615	5.639	5.768	5.843
Weight of moist red mud, (W_2-W_1) kg	1.551	1.554	1.582	1.711	1.786
Moist unit weight= (W_2-W_1)/10^{-3}(kg/m^3)	1551	1554	1582	1711	1786
Mass of moisture can,(W_3 kg)	0.020	0.020	0.020	0.021	0.021
Mass of can+moisture in red mud,(W_4 kg)	0.069	0.070	0.067	0.069	0.084
Mass of can+dry red mud (W_5 kg)	0.065	0.065	0.061	0.064	0.074
Water content (w %) = (W_4-W_5) *100/(W_5-W_3)	8.88	8.65	14.634	11.627	18.867
Dry unit weight=moist weight/1+(w%/100)	1424.50	1426.34	1380.09	1532.78	1502.51

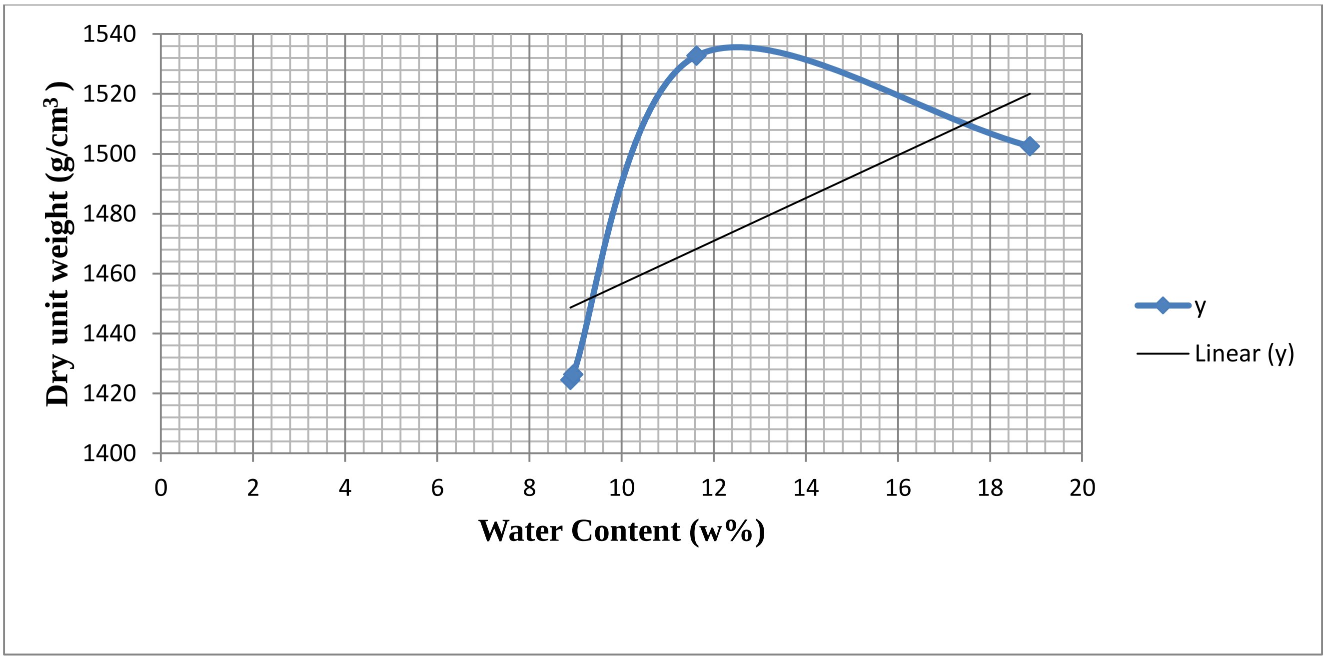


Figure 4. 4 Standard Proctor Compaction Curve (Red Mud 90% + Lime 10%)

Table 4. 4 Standard Proctor Compaction Test (Red Mud 85% + Lime 15%)

Parameters	10% water	12.5% water	15% water	17.5% water	20% water
Weight of mould(W_1) (kg)	4.060	4.060	4.060	4.060	4.060
Weight of mould(W_1)+Moist red mud, (W_2 kg)	5.615	5.646	5.750	5.843	5.879
Weight of moist red mud, (W_2-W_1) kg	1.555	1.586	1.690	1.783	1.819
Moist unit weight= (W_2-W_1)/10^{-3}(kg/m^3)	1555	1586	1690	1783	1819
Mass of moisture can,(W_3 kg)	0.020	0.020	0.020	0.021	0.021
Mass of can+moisture in red mud,(W_4 kg)	0.075	0.078	0.075	0.077	0.076
Mass of can+dry red mud (W_5 kg)	0.070	0.072	0.068	0.069	0.067
Water content (w %) = (W_4-W_5) *100/(W_5-W_3)	10.00	11.53	14.58	16.67	19.56
Dry unit weight=moist weight/1+(w%/100)	1413.63	1422.03	1474.95	1528.24	1521.41

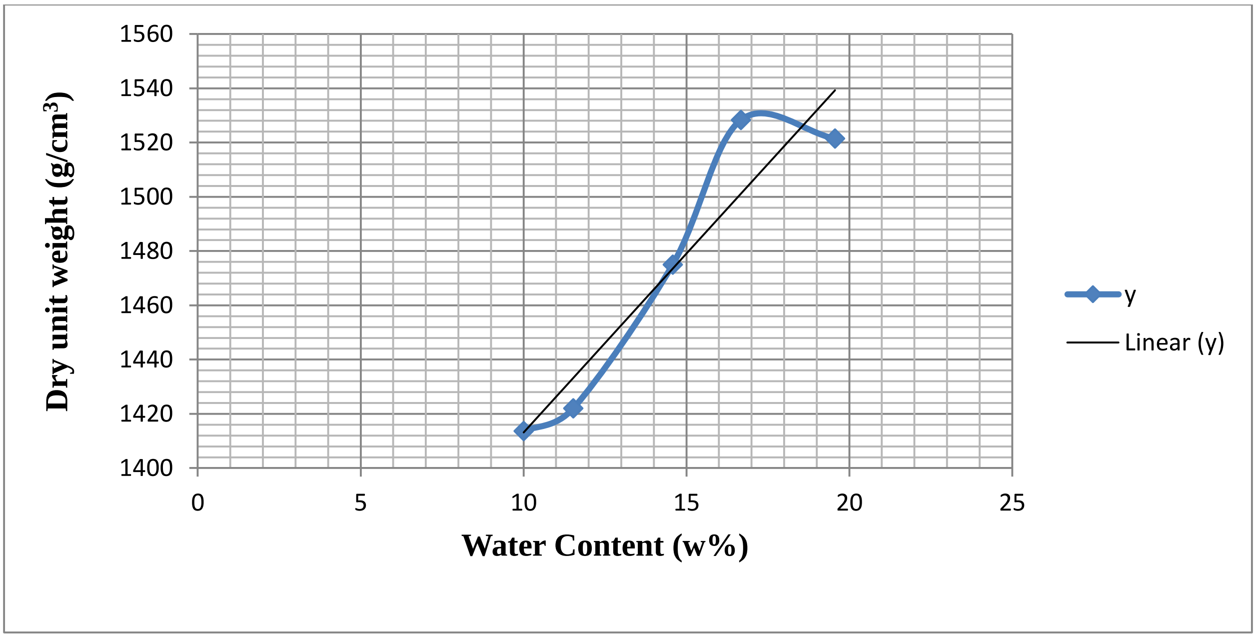


Figure 4. 5 Standard Proctor Compaction Curve (Red Mud 85% + Lime 15%)

Table 4. 5 Standard Proctor Compaction test (Red Mud 80% + Lime 20%)

Parameters	10% water	12.5% water	15% water	17.5% water	20% water	22.5% water	25% water
Weight of mould(W_1) (kg)	4.061	4.061	4.061	4.061	4.061	4.061	4.061
Weight of mould(W_1)+Moist red mud, (W_2 kg)	5.523	5.587	5.597	5.640	5.709	5.725	5.754
Weight of moist red mud, (W_2-W_1) kg	1.462	1.526	1.536	1.579	1.648	1.664	1.693
Moist unit weight= (W_2-W_1)/10^{-3}(kg/m^3)	1462	1526	1536	1579	1648	1664	1693
Mass of moisture can, (W_3 kg)	0.012	0.012	0.012	0.012	0.021	0.058	0.044
Mass of can + moisture in red mud,(W_4 kg)	0.039	0.041	0.038	0.043	0.060	0.058	0.074
Mass of can + dry red mud (W_5 kg)	0.036	0.037	0.034	0.038	0.053	0.080	0.068
Water content (w %) = (W_4-W_5) *100/(W_5-W_3)	12.50	16.00	18.18	19.23	21.875	22.72	25.00
Dry unit weight=moist weight/1+(w%/100)	1299.55	1315.51	1299.71	1324.33	1352.26	1355.90	1354.40

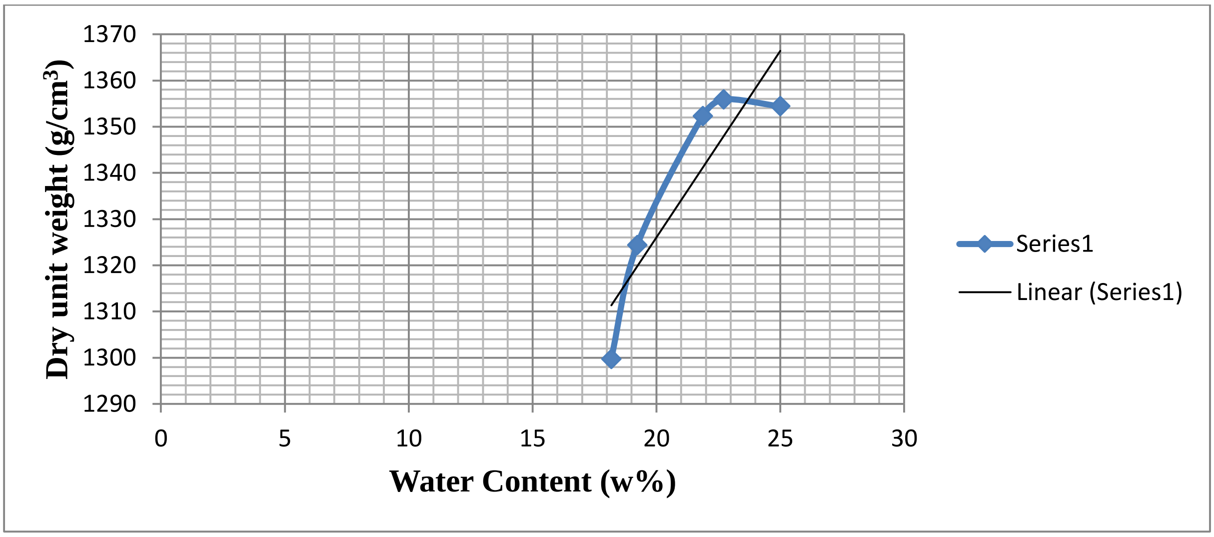


Figure 4. 6 Standard Proctor Compaction Curve (Red Mud 80% + Lime 20%)

Some results in the graph was not considered because of the unconstraint results which is due to the presence of microspores in the composite material. From the above observation table and figure, optimum moisture content of:

- Red mud (95%) + lime (5%) = 12 %
- Red mud (90%) + lime (10%) = 12.5%
- Red mud (85%) + lime (15%) = 17.5%
- Red mud (80%) + lime (20%) =22.5%.

4.5 Unconfined compressive strength

The unconfined compression test is usually made on undisturbed samples. It is reasonably simple and fast method. It provides a good supplementary test for more complex strength tests.

Plate 4. 2 Failure of sample (Unconfined compressive strength)

Table 4. 6 Failure load of composite (Red mud (95%) + Lime (5%) of 7 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	750.08
13	339.88
10	468.80

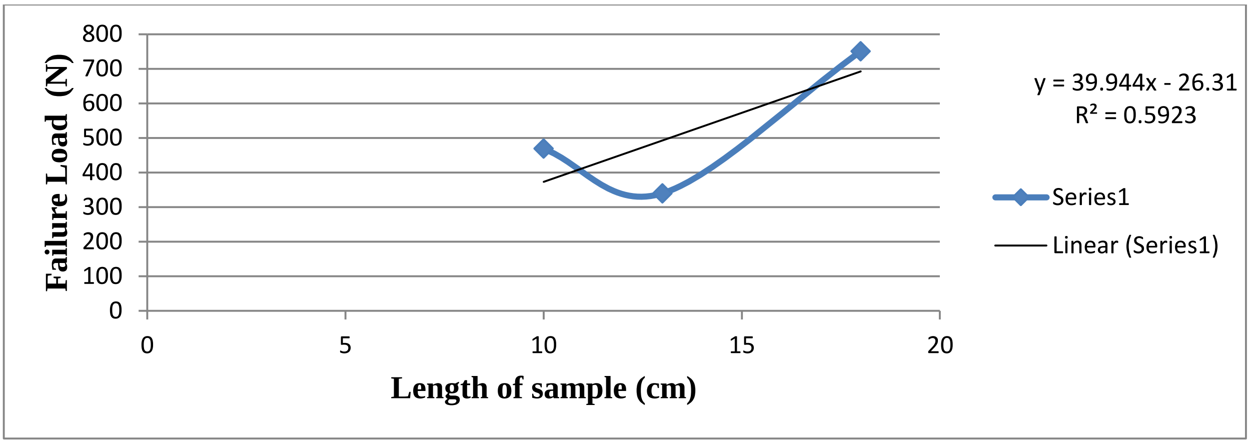


Figure 4. 7 Failure load of composite (Red mud (95%) + Lime (5%) of 7 days Curing period)

From Table 4.6 and Fig. 4.7, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 11955.69 N (1.219 ton-force).

Table 4. 7 Failure load of composite (Red mud (95%) + Lime (5%) of 14 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	703.6
13	257.84
10	480.52

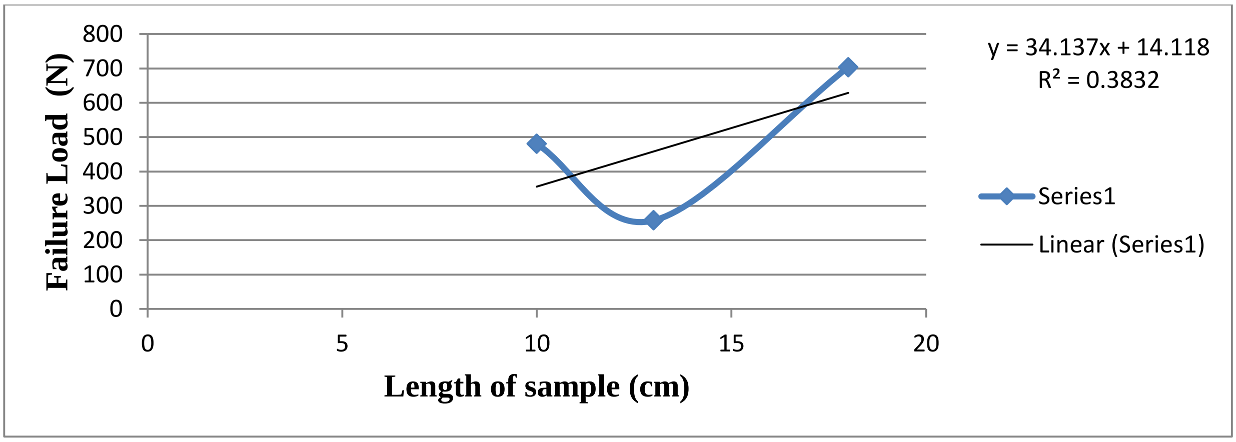


Figure 4. 8 Failure load of composite (Red mud (95%) + Lime (5%) of 14 days Curing period)

From Table 4.7 and Fig. 4.8, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 10253.11N (1.045 ton-force).

Table 4. 8 Failure load of composite (Red mud (95%) + Lime (5%) of 28 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	996.2
13	851.65
10	679.76

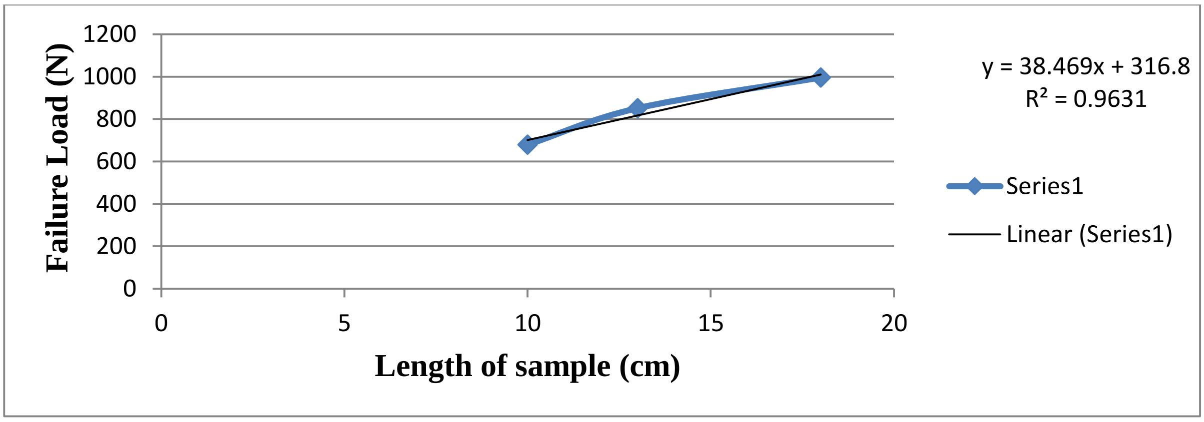


Figure 4. 9 Failure load of composite (Red mud (95%) + Lime (5%) of 28 days Curing period)

From Table 4.8 and Fig. 4.9, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 11854.80 N (1.208 ton-force).

Table 4. 9 Failure load of composite (Red mud (90%) + Lime (10%) of 7 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	7383.60
13	7305.46
10	6563.20

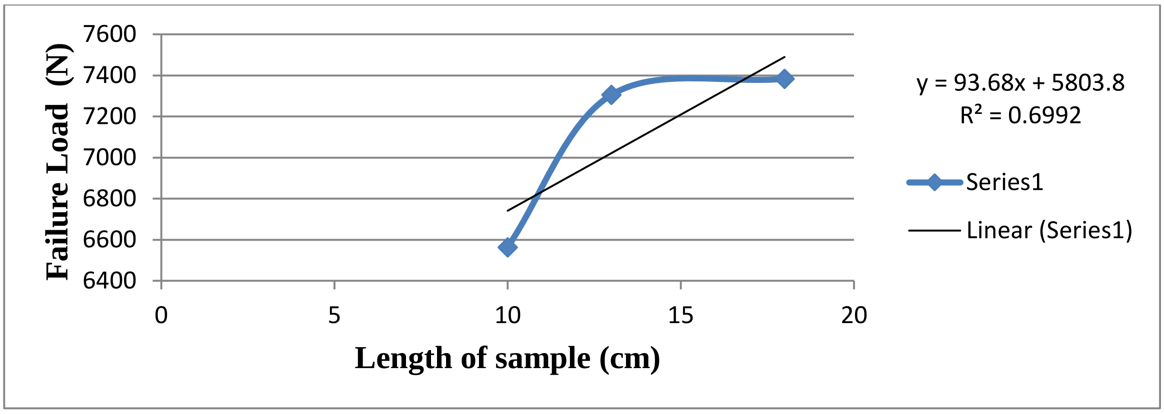


Figure 4. 10 Failure load of composite (Red mud (90%) + Lime (10%) of 7 days Curing period)

From Table 4.9 and Fig. 4.10, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 33907 N (3.457 ton-force).

Table 4. 10 Failure load of composite (Red mud (90%) + Lime (10%) of 14 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	7442.20
13	7344.53
10	7090.60

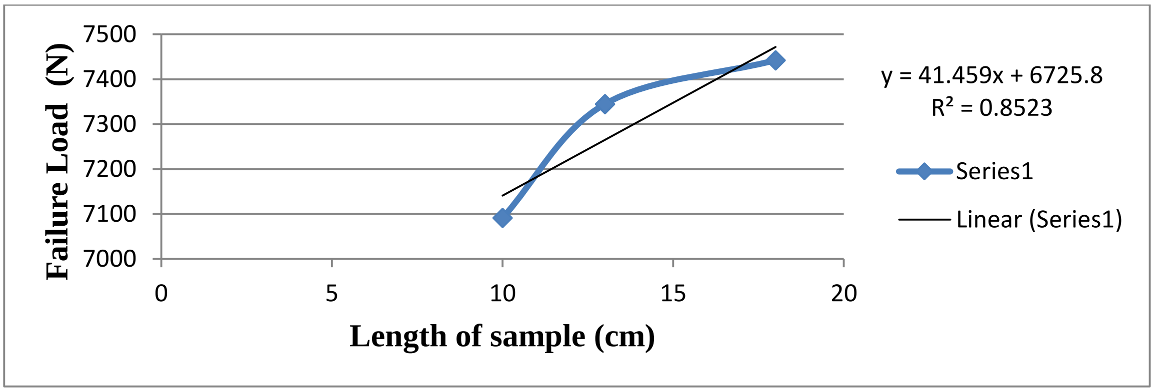


Figure 4. 11 Failure load of composite (Red mud (90%) + Lime (10%) of 14 days Curing period)

From Table 4.10 and Fig. 4.11, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 19160 N (1.953 ton-force).

Table 4. 11 Failure load of composite (Red mud (90%) + Lime (10%) of 28 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	8848.50
13	7930.50
10	7852.40

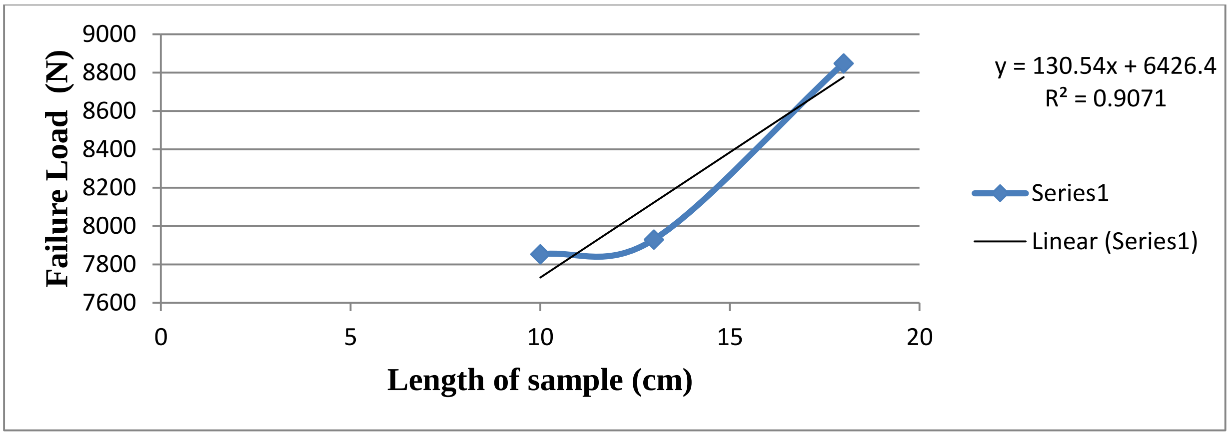


Figure 4. 12 Failure load of composite (Red mud (90%) + Lime (10%) of 28 days Curing period)

From Table 4.11 and Fig. 4.12, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 45576 N (4.647 ton-force).

Table 4. 12 Failure load of composite (Red mud (85%) + Lime (15%) of 7 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	8497.00
13	8321.20
10	8204.00

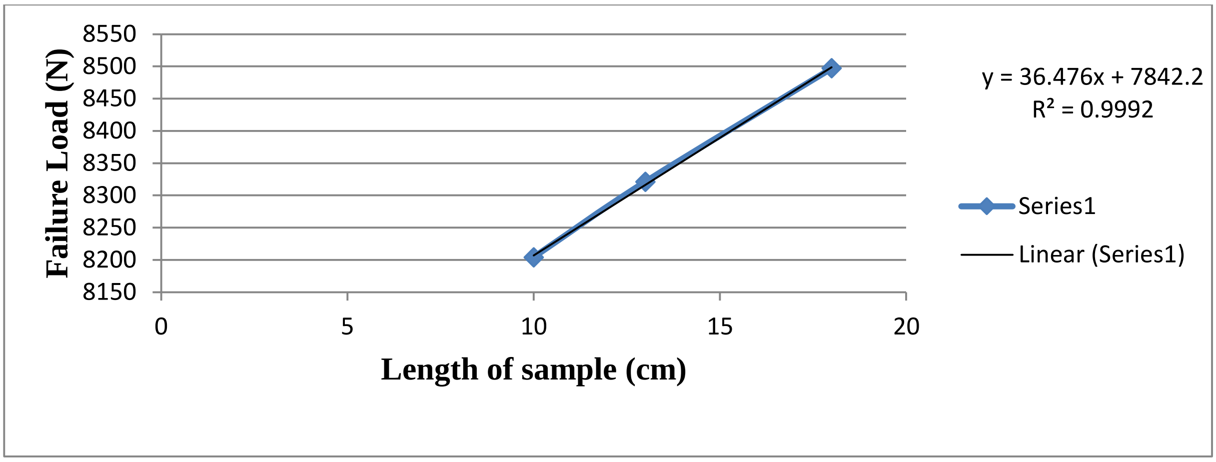


Figure 4. 13 Failure load of composite (Red mud (85%) + Lime (15%) of 7 days Curing period)

From Table 4.12 and Fig. 4.13, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 18783 N (1.915 ton-force).

Table 4. 13 Failure load of composite (Red mud (85%) + Lime (15%) of 14 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	9258.80
13	8907.20
10	8262.60

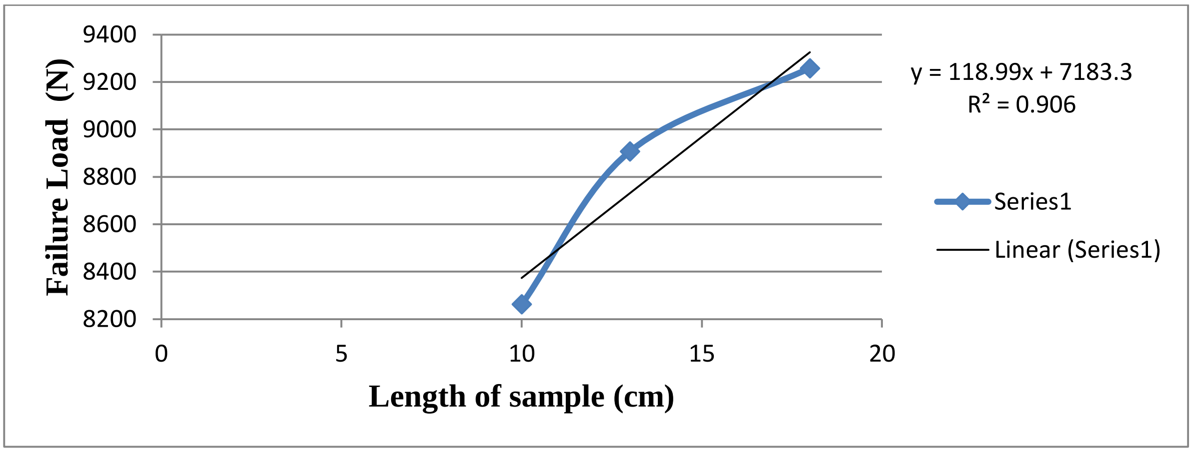


Figure 4. 14 Failure load of composite (Red mud (85%) + Lime (15%) of 14 days Curing period)

From Table 4.13 and Fig. 4.14, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 42853 N (4.369 ton-force).

Table 4. 14 Failure load of composite (Red mud (85%) + Lime (15%) of 28 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	11192.60
13	10059.66
10	9376.00

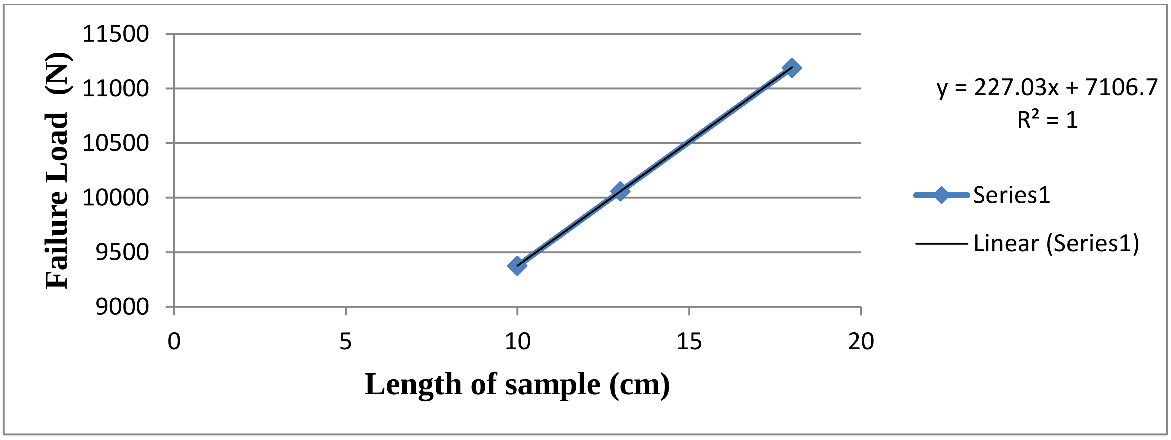


Figure 4. 15 Failure load of composite (Red mud (85%) + Lime (15%) of 28 days Curing period)

From Table 4.14 and Fig. 4.15, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 75206 N (7.668 ton-force).

Table 4. 15 Failure load of composite (Red mud (80%) + Lime (20%) of 7 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	11192.60
13	10059.66
10	9376.00

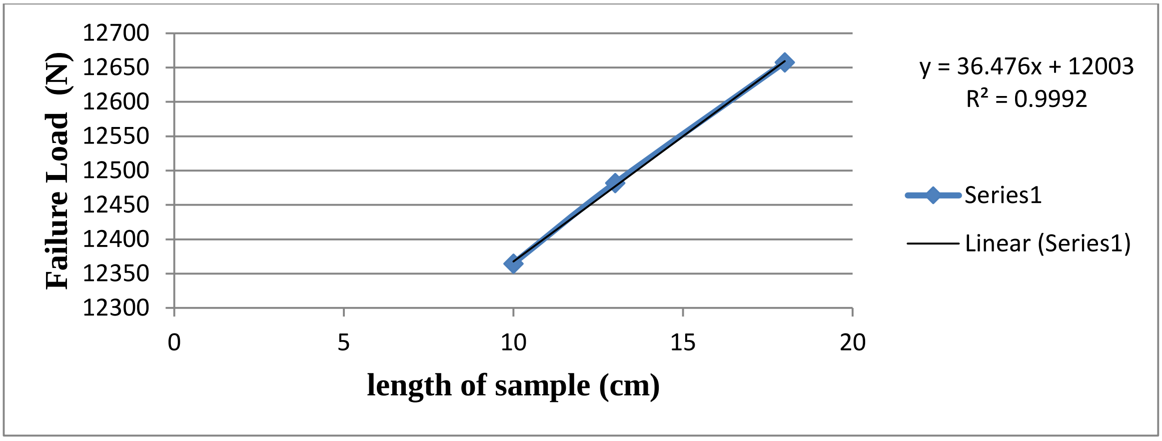


Figure 4. 16 Failure load of composite (Red mud (80%) + Lime (20%) of 7 days Curing period)

From Table 4.15 and Fig. 4.16, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 22944 N (2.339 ton-force).

Table 4. 16 Failure load of composite (Red mud (80%) + Lime (20%) of 14 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	13536.60
13	12599.00
10	12364.60

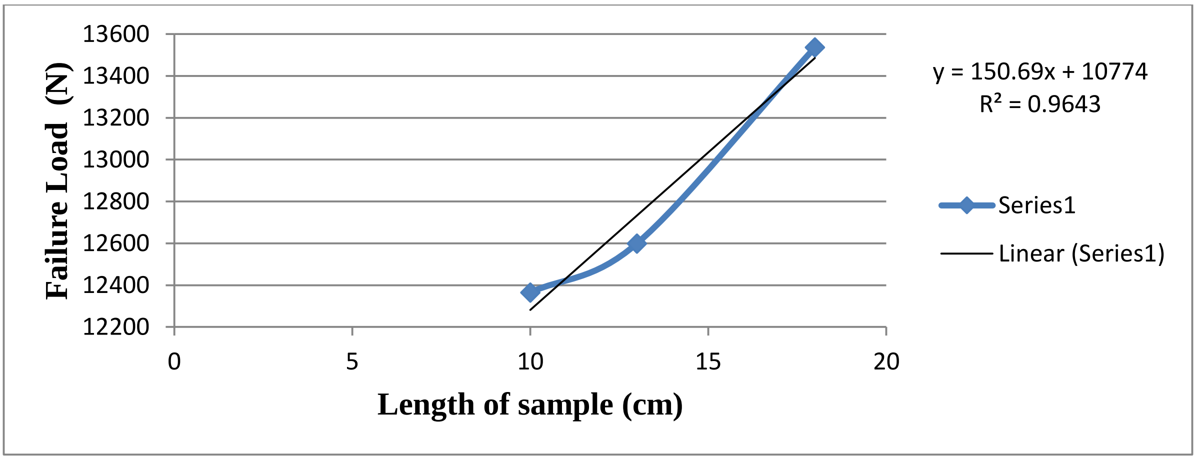


Figure 4. 17 Failure load of composite (Red mud (80%) + Lime (20%) of 14 days Curing period)

From Table 4.16 and Fig. 4.17, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 55954 N (5.705 ton-force).

Table 4. 17 Failure load of composite (Red mud (80%) + Lime (20%) of 28 days Curing period)

Length of sample (cm), X	Failure Load(N), Y
18	15529.00
13	12716.00
10	12540.40

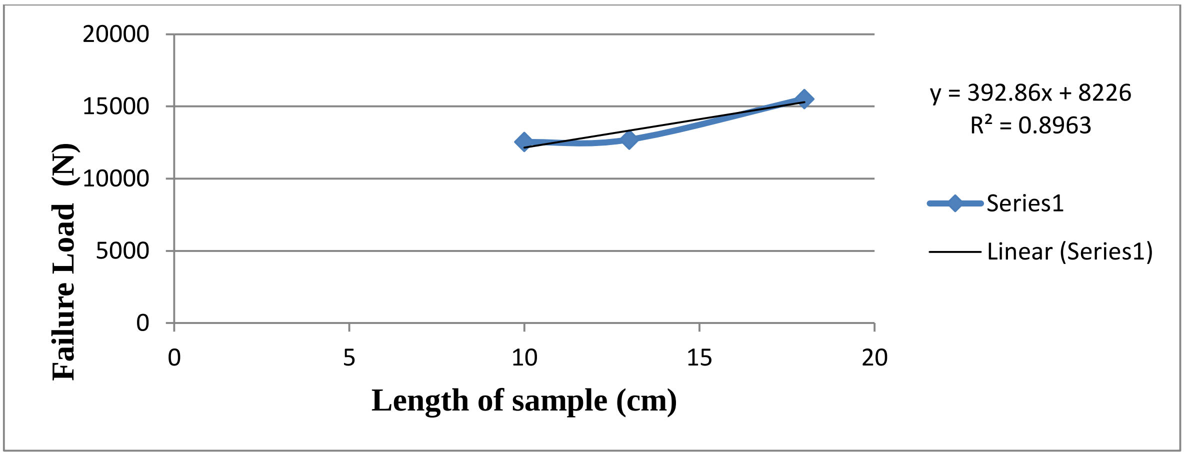


Figure 4. 18 Failure load of composite (Red mud (80%) + Lime (20%) of 28 days Curing period)

From Table 4.17 and Fig. 4.18, we are coming to the conclusion that for a composite of 3 m length and 6 cm diameter, the failure load should be 126066 N (12.855 ton-force).

Observation for unconfined compressive strength

From the observation of failure load of red mud based composite material and optimum moisture content, UCS of composites are calculated and represented in table 4.18-4.21.

Table 4. 18 UCS of composite (Red mud (95%) + Lime (5%))

Curing Period	Length (cm)	Diameter (cm)	Optimum moisture content	Failure load (tones)	Unconfined compressive strength (Kg/cm^2)
7 days	300	6	12%	1.21	43.12
14 days				1.04	36.98
28 days				1.20	42.76

Table 4. 19 UCS of composite (Red mud (90%) + Lime (10%))

Curing Period	Length (cm)	Diameter (cm)	Optimum moisture content	Failure load (tones)	Unconfined compressive strength (Kg/cm^2)
7 days	300	6	12.5%	3.457	122.30
14 days				1.953	69.11
28 days				4.647	164.39

Table 4. 20 UCS of composite (Red mud (85%) + Lime (15%))

Curing Period	Length (cm)	Diameter (cm)	Optimum moisture content	Failure load (tones)	Unconfined compressive strength (Kg/cm^2)
7 days	300	6	17.5%	1.915	67.75
14 days				4.369	154.57
28 days				7.668	271.20

Table 4. 21 UCS of composite (Red mud (80%) + Lime (20%))

Curing Period	Length (cm)	Diameter (cm)	Optimum moisture content	Failure load (tones)	Unconfined compressive strength (Kg/cm^2)
7 days	300	6	22.5%	2.33	82.76
14 days				5.70	201.82
28 days				12.85	454.72

From the above observation, we are getting maximum failure load and unconfined compressive strength in the composition of Red mud (80%) + Lime (20%) of 28 days of curing period i.e. 12.85 tones and 454.72 Kg/cm^2 respectively.

4.6 Tensile Strength

Tensile strength is an important property to predict the cracking behaviour of pavement, structures using stabilized materials. All the specimens failed more or less at the middle through an induced force which is tensile in nature.

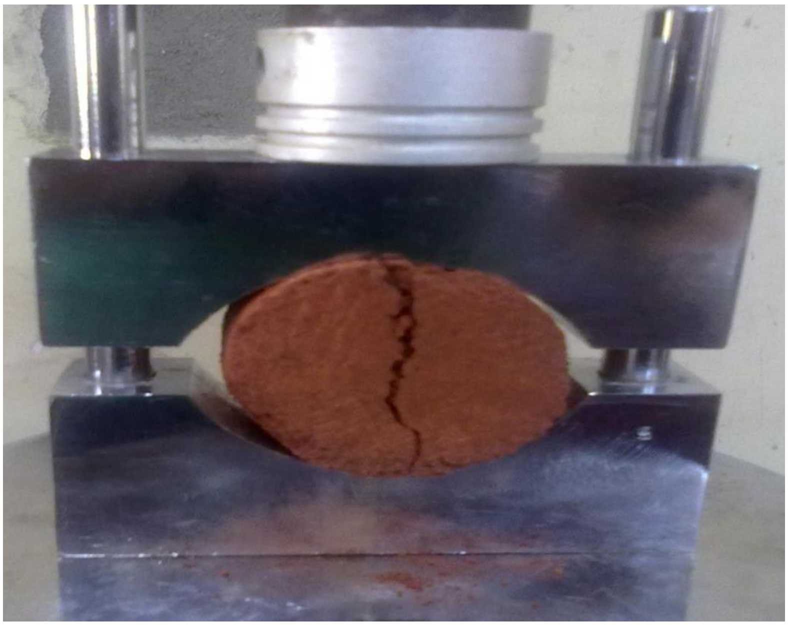


Plate 4. 3 Failure of sample (Tensile strength test)

Table 4. 22 Tensile Strength of composite (Red mud (95%) + Lime (5%))

Curing Period	Failure Load (N)	Tensile Strength ($\sigma_t = 2P/\pi DL$) (Kg/cm^2)	Average Tensile Strength (Kg/cm^2)
7 days	586.85	2.10	2.16
	610.27	2.20	
	610.27	2.20	
14 days	761.80	2.74	2.43
	644.60	2.32	
	621.16	2.24	
28 days	879.00	3.17	2.56
	586.85	2.11	
	668.04	2.40	

Table 4. 23 Tensile Strength of composite (Red mud (90%) + Lime (10%))

Curing Period	Failure Load (N)	Tensile Strength ($\sigma_t = 2P/\pi DL$) (Kg/cm^2)	Average Tensile Strength (Kg/cm^2)
7 days	3867.60	13.95	14.72
	4277.80	15.43	
	4102.00	14.79	
14 days	4160.50	15.00	15.35
	4277.80	15.43	
	4336.40	15.64	
28 days	4453.60	16.06	16.20
	4453.60	16.06	
	4570.80	16.48	

Table 4. 24 Tensile Strength of composite (Red mud (85%) + Lime (15%))

Curing Period	Failure Load (N)	Tensile Strength ($\sigma_t = 2P/\pi DL$)(Kg/cm^2)	Average Tensile Strength (Kg/cm^2)
7 days	4981.00	17.96	16.97
	4395.00	15.85	
	4746.60	17.12	
14 days	5274.00	19.02	19.72
	5567.00	20.08	
	5567.00	20.08	
28 days	6153.00	22.19	21.27
	5860.00	21.13	
	5684.20	20.50	

Table 4. 25 Tensile Strength of composite (Red mud (80%) + Lime (20%))

Curing Period	Failure Load (N)	Tensile Strength ($\sigma_t = 2P/\pi DL$) (Kg/cm^2)	Average Tensile Strength (Kg/cm^2)
7 days	7032.00	25.36	24.30
	6739.00	24.30	
	6446.00	23.25	
14 days	8204.00	29.59	29.16
	7911.00	28.53	
	8145.40	29.38	
28 days	8555.60	30.86	30.57
	8614.20	31.07	
	8262.60	29.80	

From the observation, we can conclude that composite of red mud 80% and lime 20% with curing period of 28 days has the highest tensile strength i.e. 30.57 Kg/cm^2.

4.7 Economic evaluation and handling of red mud based composite

Weight of sample having length of 13cm and diameter of 6cm = 620 g

If length = 300 cm then weight of prop = 300* 620/13 = 14307.69g = 14.30769 Kg

Weight of the lime in one sample having length 300cm and diameter 6cm = 14.30769* 20/100 = 2.86 kg i.e. 2.86 kg of lime is required for a red mud based composite prop of 80% red mud and 20% lime.

Cost of lime of A-grade = 470 Rs/Kg.

Then the cost of lime required for a prop = 2.86* 470 = Rs.1344.2

So, the weight of the prop having 300cm length and 6cm diameter = 14.30kg which is easier to handle from one place to another and cost of one red mud based composite prop = Rs. 1344.2. Carrying cost of red mud is 50 paisa to 1 rupee per Kg depends upon the distance of transportation and the mode of transport should be added to the cost of composite based prop.

The timber props contribute the maximum volume of roof support system in underground mines. Huge consumption of timber support in underground mines leads to deforestation and ecological disturbance in environment. The red mud may also be used as replacement of timber props [26].

Chapter 5

Conclusion

Chapter: 5

Conclusion

5.1 Conclusion

- NALCO, Damanjodi red mud has rich in iron content (49.75%) and can be used for mining applications where the higher strength is required.
- A-grade lime was used to enhance the strength of red mud based composite material as a binding agent.
- Composite of 80% red mud and 20% lime of 28 days curing period has maximum failure load of 12.85 tone and higher unconfined compressive strength as 454.72 Kg/cm^2.
- The weight of the prop having 300cm length and 6cm diameter = 14.30kg and the cost of one red mud based composite prop = Rs. 1344.2 and 50 paisa to 1 Re carrying cost should be added depending upon the transportation distance and the mode of transport.

5.2 Scope for future work

Due to time constraint, the following work could not be covered in this thesis and research should be possible in future:

- Environmental impact of red mud.
- Different proportion of red mud and lime content can be used with higher curing period and varying length and diameter can be investigated with cost and handling analysis of support.

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